DDF annual report

Title of Investigation:

Large Depth of Field, High Spatial Resolution Particle Image Velocimeter (PIV) for In Situ Characterization of Martian Dust Cyclone Particle Dynamics

Principal Investigator:

Dr. Brent J. Bos (Code 551)

Other External Collaborators:

Dr. Stephen Metzger (Planetary Science Institute)

Initiation Year:

FY 2005

Funding Authorized for FY 2005:

$56,000

Actual or Expected Expenditure of FY 2005 Funding:

Equipment purchase: $6,000; Metzger field costs: $5,000

Status of Investigation at End of FY 2005:

FY 2006 (DDF extension granted)

Expected Completion Date:

September 2006

Purpose of Investigation:

Dust plays an important role in the atmosphere of Mars. It governs atmospheric temperatures because it absorbs solar radiation and it allows H_2O and CO_2 frost to form. Dust also drives the weathering processes on the surface of rocks. Therefore, understanding how Martian dust particles migrate from the surface to the atmosphere and back down again is crucial to understanding the planet. An important consideration is the role of cyclones or "dust devils" in the development of the global dust storms on Mars. Knowledge about the dust hazards will be critical to the design of a manned Mars mission. The 2002 NRC report "Safe On Mars" agrees, recommending that future robotic Mars missions characterize Martian soil and airborne dust to assess their potential impact on a manned mission. We intend to develop, build, and field test a proof-of-concept instrument capable of measuring dust-particle size and velocity from within a dust cyclone without first capturing the dust particle. Such instruments are known as particle-image velocimeters (PIV).

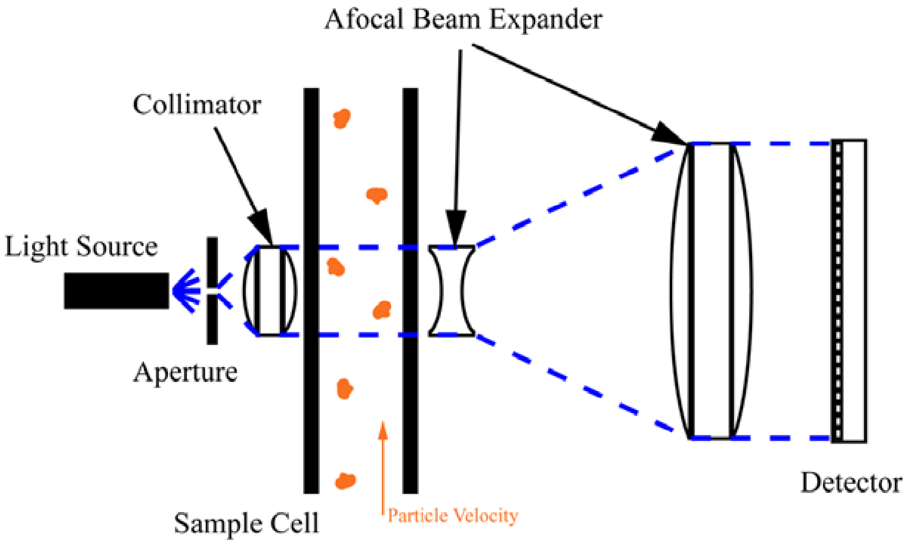

Figure 1. Conceptual Mars PIV layout

The conceptual layout is shown in Figure 1. When dust particles travel through a collimated beam of light, they cast shadows. Since dust-particle shadows are detected, the instrument's depth of field can be extremely large, resolving dust particle sizes from 1-200 µm. For slow-moving particles, two image frames are used to calculate velocity. For fast-moving particles, the length of the image smear and the size of the particles are used to determine particle velocity.

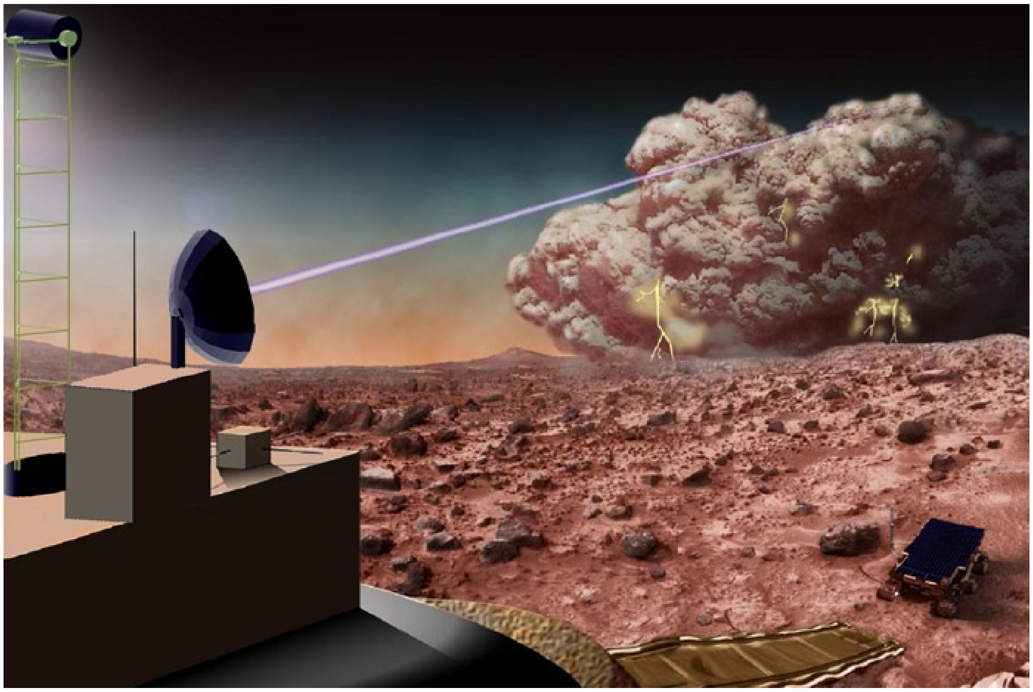

Figure 2. Illustration of the MASST instrument suite concept

Accomplishments to Date:

Due to the late March 2005 notification that this work was selected for funding and the delay in availability of funds until April 8, 2005, the original FY 2005 goals of this work were significantly scaled back. The instrument could not be constructed in time for an early June "dust devil" field experiment. In addition, the expiration of the awarded funds at the end of FY 2005 meant that the entire effort needed to be completed in less than 6 months.

Given the severe programmatic limitations, we decided, nonetheless, to take advantage of the 2005 dust-devil season and make dust-cyclone measurements to guide specifications for the Mars PIV. The primary areas of interest included dust-cyclone rotational velocity and particle-flux density. Dust devil rotational velocity, together with the beam-expander magnification ratio, determines the required frame rate of the PIV detector. The expected particle-flux density influences the size of the PIV measurement volume.

To measure dust devil velocities, we collaborated with Stephen Metzger of the Planetary Science Institute to make *in situ* observations of naturally occurring dust devils in Eloy, Arizona. We accomplished this by rigging a chase vehicle with an instrumented, 5-m tall mast and driving the vehicle into the path of oncoming dust devils. Figure 3 shows the chase vehicle. The dust-flux instruments were purchased off-the-shelf specifically for this research. The anemometers were already available from a previous effort.

Figure 3. Collaborator Stephen Metzger Dust provided the chase vehicle with a 5-m mast.

Our field experiment took place from June 6-11, 2005. It was very successful. We measured several significant dust devil events and acquired the dust cyclone's velocity and dust flux needed to develop the PIV specifications. Figure 4 shows the dust-flux data from a medium-size dust devil that we were able to intercept. The dip in the particle flux and the equal double peaks indicate that the eye of the vortex passed directly over the sensors. The entire event lasted approximately 10 seconds. Figure 5 shows the horizontal wind speeds measured during an encounter with the large, long-duration (>30 minutes) dust vortex shown in Figure 6. For this particular encounter, the maximum horizontal wind speed was 15 meters per second.

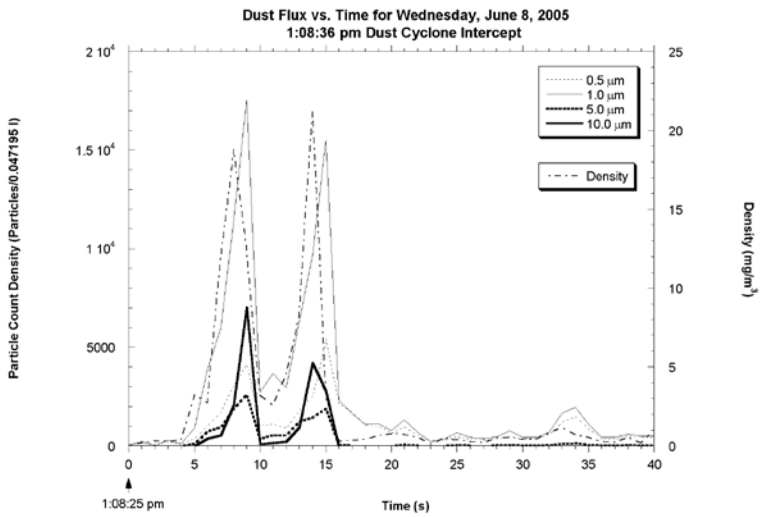

Figure 4. Dust cyclone dust flux data measured during the 2005 field campaign

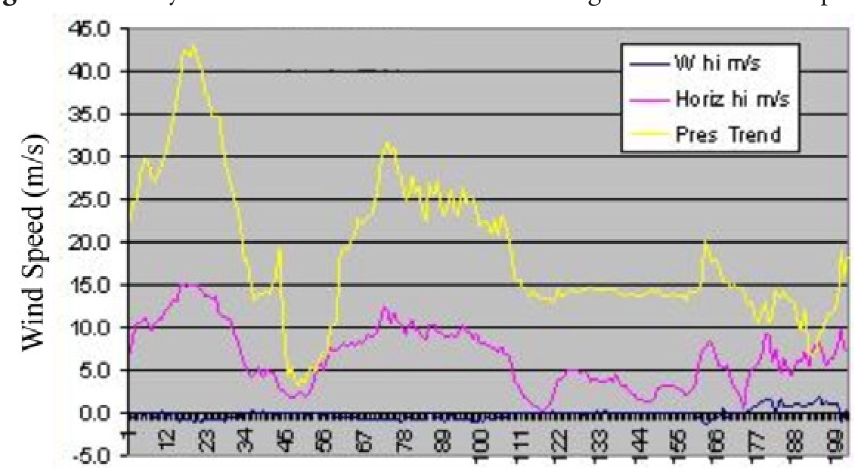

Figure 5. Dust cyclone rotational velocities measured during the 2005 field campaign

Figure 6. A large dust cyclone encountered during the 2005 field campaign

In addition to the June field experiment, we have pursued a combined laboratory and simulation effort to determine how well we will be able to interpret particle sizes in the PIV images. Due to the afocal operation of the sensor, Fresnel or near-field diffraction effects will be plainly evident in the images of small particles. To determine how well our diffraction model predicts the images for small particles, we set up a collimated beam of light in the laboratory, placed stationary particles of various sizes (5-30 µm) in the collimated beam, and captured the irradiance pattern with a detector. A comparison of a predicted image and an actual laboratory image are shown in Figure 7. The results of this investigation indicate that our diffraction model is of high enough fidelity to allow proper interpretation of the PIV images.

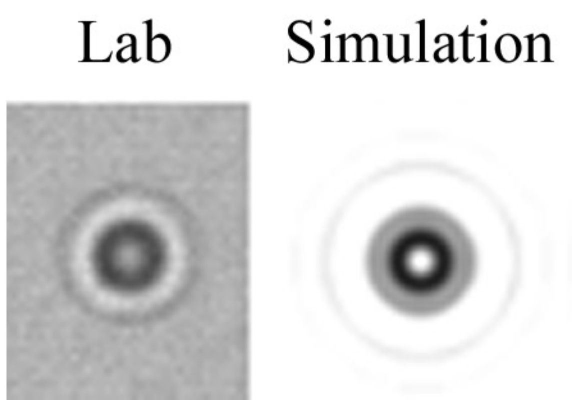

Figure 7. Comparison of predicted and measured dust particle diffraction patterns

Publications and Conference Presentations:

- There have been two conference presentations of this work:

  Brent J. Bos, Bruce Gentry, William M. Farrell, Telana L. Jackson, Stephen Metzger, Joseph P. Comer, Jeremy Dobler, Gerald S. McIntire, Catherine Neish, Peter H. Smith, and Robert Atlas, "Dust devil observations from the 2005 MASST field experiment," presented at the Flagstaff, Arizona, Workshop on Dust Devils: Earth and Mars, September 19-20, 2005.

- Stephen Metzger, Brent J. Bos, Stephen D. Fuerstenau, Matt Balme, William M. Farrell, Ron Greeley, Timothy Ringrose, and Martin Towner, "Dust devil studies on Mars analog arid surfaces," presented at the 2005 Salt Lake City Geological Society of America Annual Meeting, October 16-19, 2005.

This work also has been published in several media outlets including:

- "Dust devils may aid Mars mission," *Arizona Daily Star*, June 14, 2005.

- "Phantoms From the Sand: Tracking Dust Devils Across Earth and Mars," http://www.nasa.gov/vision/universe/solarsystem/2005_dust_devil.html.

In addition, the Mars documentary, "The Right Stuff," is expected to air on the Discovery Channel in the Spring 2006.

Planned Future Work:

With the project extension granted by the DDF program, we will pursue in FY 2006 the original goals of the Mars PIV research. If the funding is available in time, we will construct a proof-of-concept PIV instrument and make field measurements in June 2006. Otherwise, 2006 will consist of only instrument fabrication and we will have to delay the field test until 2007.

Key Points Summary:

Project's innovative features: This is the first instrument that we are aware of that will be capable of measuring dust cyclone particle sizes and velocities throughout a large volume of space.

Potential payoff to Goddard/NASA: NASA/GSFC is developing several Mars dust instrumentation/mission concepts. A successful demonstration of this technology will enhance those efforts.

The criteria for success: This development effort will be considered successful when the proof-of-concept instrument successfully measures the distribution of particle sizes and velocities in naturally occurring dust devils on Earth.

Technical risk factors: Based on our FY 2005 field experiment cyclone velocity measurements, we know that capturing images of small dust particles in flight will push the state-of-the-art in solid-state detector frame rates. We require rates on the order of 3,000 frames per second. Image sub-framing and relaxation of the resolution goal most likely will be necessary to meet this requirement. We will be exploring this trade space in selecting the instrument's detector.